

GEOPHYSICAL INVESTIGATIONS

APPENDIX D

to

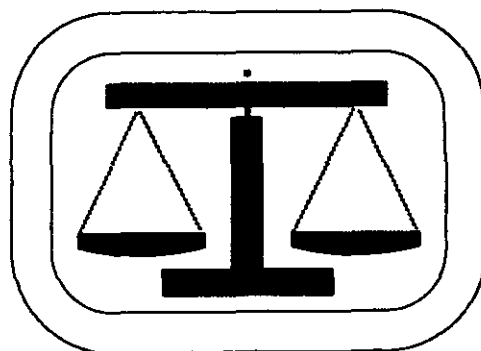
Contract Number DACW-33-81-D-0005

Work Order Number 0007

Coastal Flood Study

Revere, Massachusetts

August 24 through September 3, 1982



BRIGGS

**GEOTECHNICAL ENGINEERING
BRANCH**

GEOPHYSICAL INVESTIGATIONS
REVERE COASTAL FLOOD PROTECTION STUDY
POINT OF PINES
REVERE, MASSACHUSETTS

Prepared for
BRIGGS ENGINEERING & TESTING COMPANY

October 1982



Weston Geophysical
CORPORATION

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1.0 INTRODUCTION AND PURPOSE

A geophysical survey was conducted for Briggs Engineering & Testing Company under U.S. Army Corps of Engineers contract, in Revere, Massachusetts in the vicinity of Point of Pines on September 8 and September 9, 1982.

The purpose of this survey was to determine if extensive organic materials are present immediately beneath the surficial sandy material. Ground penetrating radar and resistivity were the geophysical techniques selected to investigate the presence of organic materials at this locale. If extensive organic materials are present, they would likely be evidenced as areas of anomalous reflection data, depending on the water (either a moisture condition or a saturation condition) contained within the organic zone. Descriptions of the ground penetrating radar and resistivity techniques are included as Appendix A and Appendix B, respectively to this report.

The area of investigation and survey line were established by the U.S. Army Corps of Engineers and shown as Attachment 2 in the GEB Requisition No. 82-7. Field operations were coordinated with Mr. Nicholas Laney of Briggs Engineering; Weston's geophysicist for this project is E. N. Levine and the Weston senior field supervising person on site for data acquisition is B. Marshall.

The survey consisted of a ground penetrating radar line approximately 4,200 feet in length and five (5) resistivity point tests.

2.0 LOCATION AND SURVEY CONTROL

The survey area is shown on the area of investigation map, Figure 1. This map is a section of the Lynn, Massachusetts 7 1/2 minute quadrangle sheet.

3.0 PRESENTATION OF RESULTS

3.1 Ground Penetrating Radar

The results of the ground penetrating radar (GPR) survey are presented in profile form on Figures 3 and 4. The upper portion of these figures are reproductions of the ground penetrating radar records obtained in the field. The lower portion of the figures are profiles developed from the record sections showing the major reflecting interfaces that were detected.

The location of the GPR profile is shown by the mark numbers indicated on the plan map (Figure 2). The vertical scale is approximate; it was established by the resistivity point test and boring information at Boring FD-82-6.

3.2 Resistivity Point Tests

The results of the five resistivity point tests are shown in graphical form and have been included in Appendix B. The graphical resistivity plots show apparent resistivity values referenced to Wenner electrode spacings. The observed

resistivity curves, compared with theoretical curves, and the vertical electrical profiles determined by computer matching are also shown on Figures B-2 to B-6 of Appendix B.

4.0 DISCUSSION OF RESULTS

Subsurface penetration by the ground penetrating radar was achieved between Marks 6 and 15 as shown on Figures 3 and 4. Three resistivity point tests in this area show similar characteristics, that is, a near surface layer of moderate resistivity with values of 1,770 to 4,400 ohm feet underlain by material with a very low resistivity ranging from 2 to 23 ohm feet. These very low resistivity values are interpreted to be due to a salt water interface (possibly only brackish). The higher resistivity values indicated at depth by the computer modeling are not considered totally reliable because of the relatively few data points which control the appropriate portion of the resistivity curves at larger Wenner electrode spacings of 50 to 100 feet. The most definitive correlation exists at boring FD-82-6 where a resistivity point test as well as the continuous ground penetrating radar coverage was obtained. The computer model depth of 6 feet on the resistivity data corresponds well with the groundwater level of 4 feet determined by the test boring, especially when tidal conditions are taken into account. The ground penetrating radar shows a fairly strong reflecting horizon on either side of this location which is interpreted to be the salt water

interface. The general horizontal layering indicated by the ground penetrating radar between Marks 6 and 15 is disturbed in the vicinity of Boring FD-82-6; the cause of this near surface disturbance is not known.

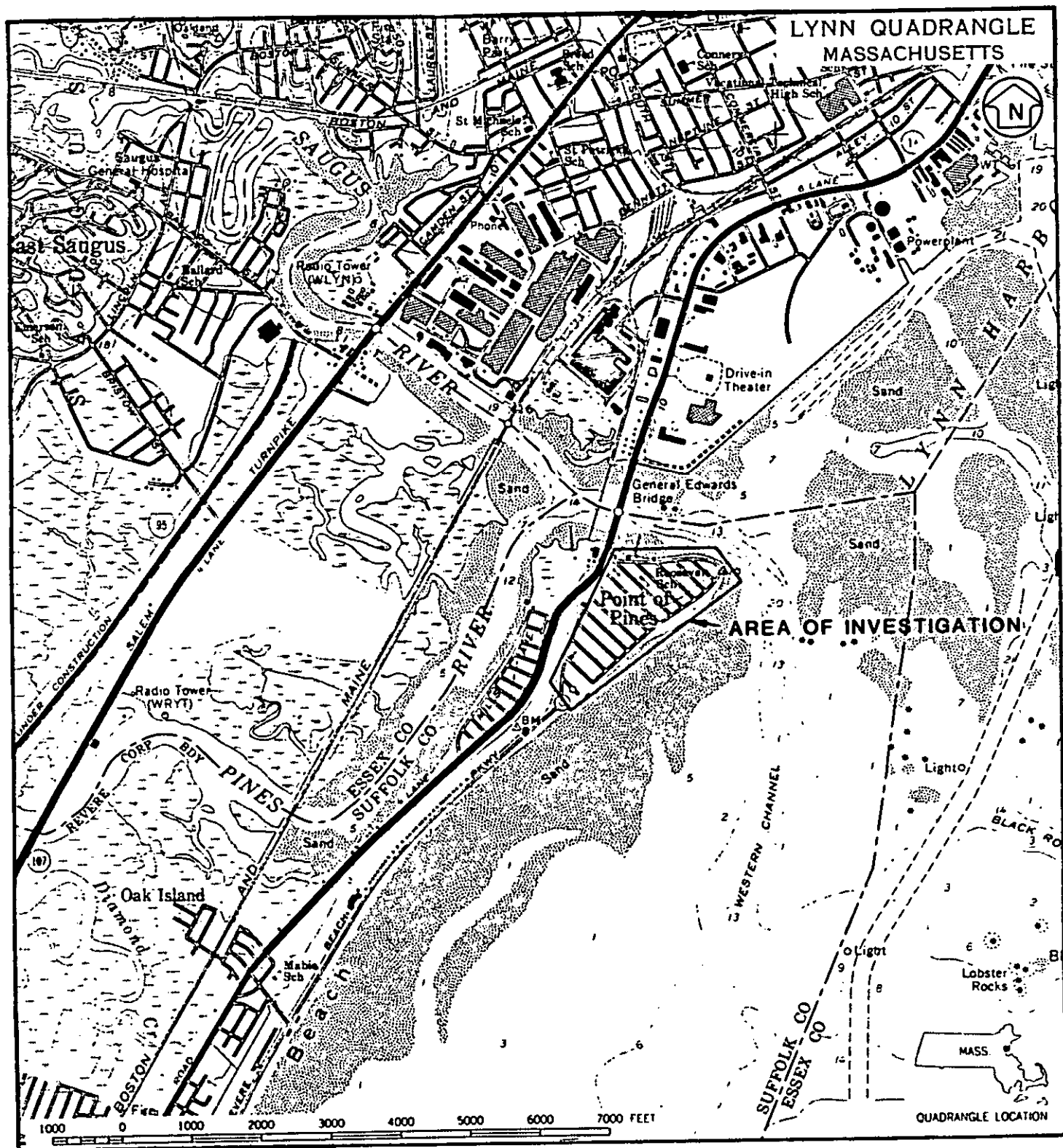
As the ground surface elevation of the radar profile increased above mean high water, the depth of penetration indicated on the GPR record also increased, further indicating that the GPR was penetrating to the salt water interface. To the southwest of Mark 5 and to the northwest of Mark 15, in areas closer to the mean high water and mean sea level line, no effective penetration was achieved by the GPR technique. The point tests located at Boring FD82-3 and between Marks 17 and 18 show very low resistivity values indicative of salt water very near or at ground surface. This would account for the little or no penetration achieved by the GPR technique in this area. In those areas which were wet or damp, the ground penetrating radar produced a ringing type of signal as shown in the vicinity of mark 16. In other areas such as in the vicinity of Mark 17, very limited penetration may have been achieved by the GPR technique, however, the remainder of the record would appear to be transparent due to the lack of penetration by the GPR. The only anomalous data indicated by the GPR data is in the vicinity of Boring FD82-6 where there is a near-surface disturbed area. A high resistivity value is also indicated at depth by the theoretical modeling of the point test data at this location.

5.0 CONCLUSIONS

The ground penetrating radar and electrical resistivity data obtained at Point of Pines provide definitive indication of reflecting horizons in some instances, and very limited penetration in other locations; this varying effect is probably due to varying depths to salt or brackish water.

The existence of extensive organic zones would probably be evidenced as anomalous zones where penetration was achieved and layering could not be discerned. Since that specific type of anomaly was not observed within the section of penetration, no positive indication of organics was obtained. If such zones exist at this site, they are either too thin to allow detection or occur below the salt (brackish) water interface.

FIGURES

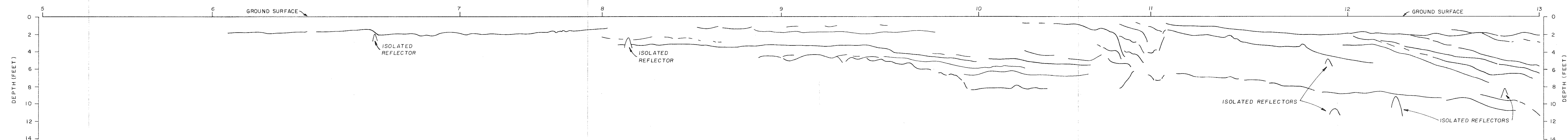
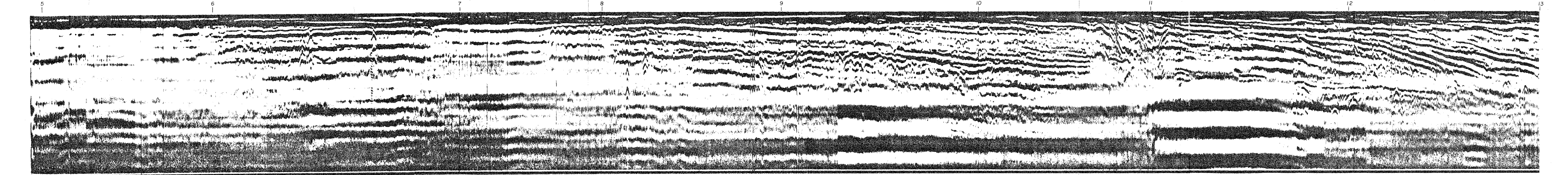
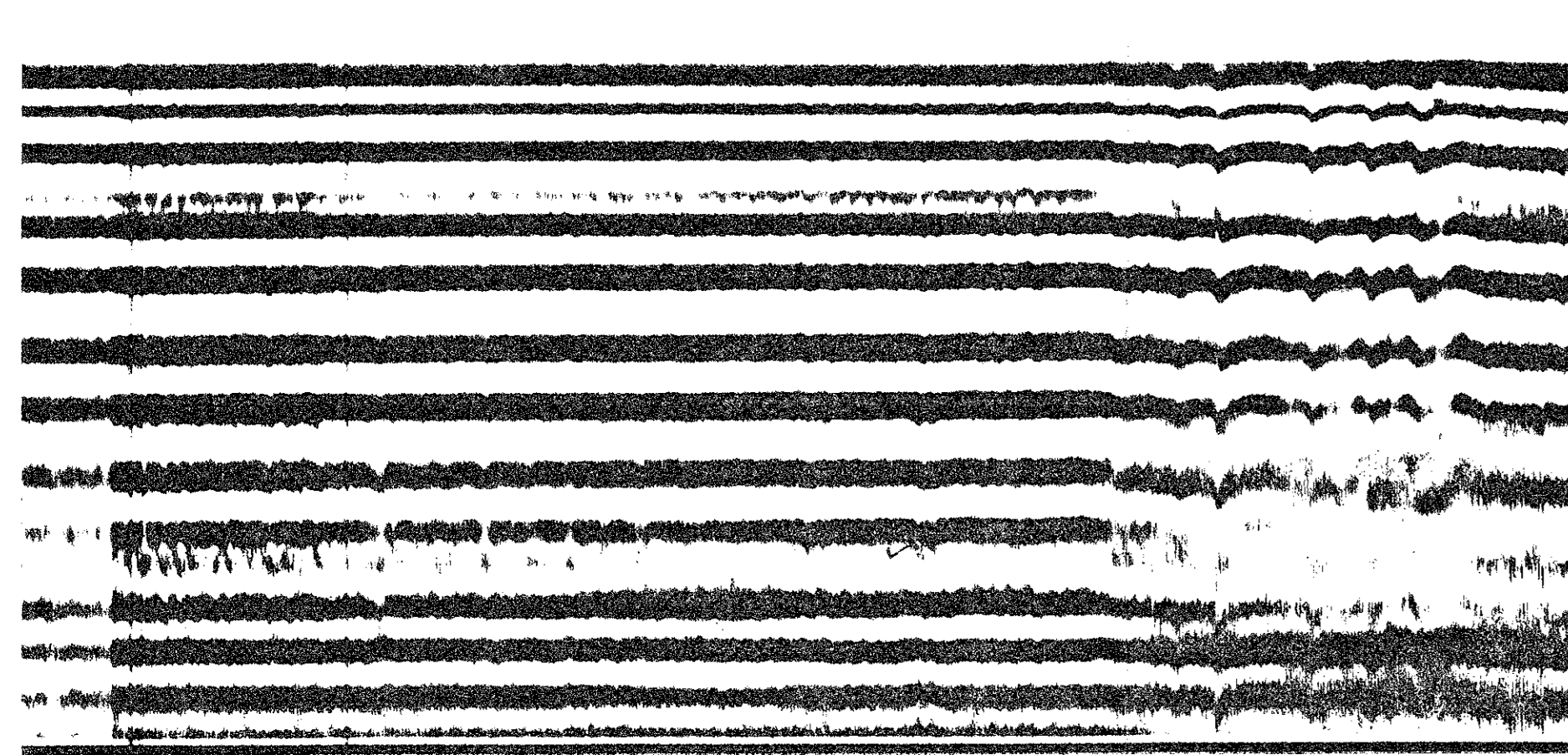


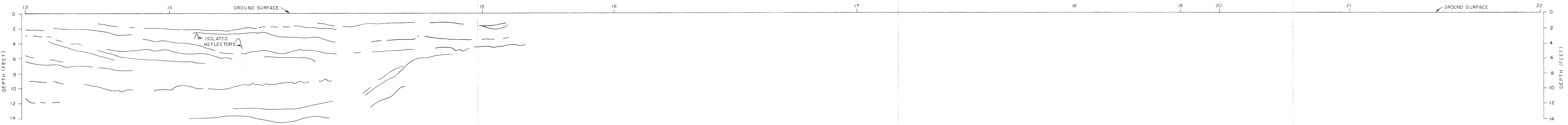
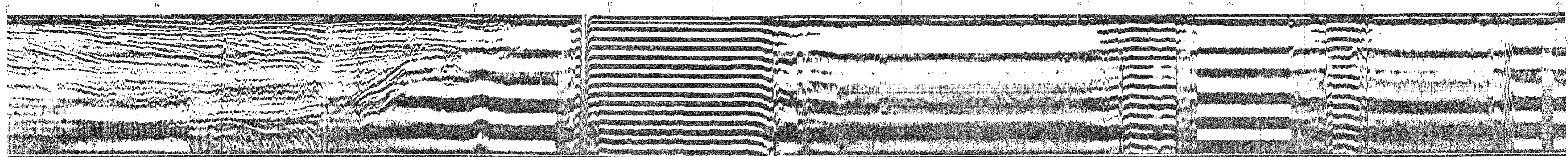
**GEOPHYSICAL INVESTIGATION
REVERE COSTAL FLOOD PROTECTION STUDY
POINT OF PINES
REVERE, MASSACHUSETTS
for
BRIGGS ENGINEERING & TESTING CO.**

AREA OF INVESTIGATION

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September 1982

Figure 1





APPENDIX A
RADAR PROFILING

APPENDIX A

RADAR PROFILING

Ground penetrating radar is an electromagnetic survey technique that reveals in cross-section a pictorial view of the material below the ground surface. Because it is an echo ranging technique, it resembles the single-trace acoustic method commonly used in marine sub-bottom profiling in which reflective layers are traced by the echo patterns they generate in response to acoustic impulses. The two techniques differ in that the acoustic method transmits sonic waves through a water medium to the material under investigation and requires time measurements accurate to fractions of milliseconds (10^{-3} seconds). Radar, on the other hand, transmits impulses of radio waves directly into the surface and requires time to be measured accurately to nano seconds (10^{-9} seconds).

In the radar system (Figure 1) high-frequency impulses of radio energy are generated by the transmitter. A beam of these impulses is emitted by a special antenna placed in close proximity to the ground so that it couples electromagnetically to the surface material. Each impulse propagates into the earth. At reflective interfaces, part of the signal is reflected while part is transmitted still deeper to be reflected by other layers or isolated reflecting bodies. Thus, for each impulse transmitted, a string of reflected impulses is

returned to the antenna in a time sequence proportional to the round-trip travel time to each reflector. After transmitting the outgoing pulse, the system instantly switches from the transmitter to the receiver in order to detect the weak echoes. While peak transmitted power may be about 35 watts, average power is only a few milliwatts. Attenuation in the ground, reduces the signal amplitude by many decibels. To detect the echoes, the receiver must exhibit both high gain and low noise characteristics.

The high frequency radar signals (typically between 80MHz and 900MHz) must be shifted down to the audible range to be recorded on ordinary magnetic tape and graphic recorders. A time-domain sampling system is used to generate a replica of the received echo waveform. This is done by sampling the echo pattern repeatedly at successively later times. Typically, the repetition rate is 50,000 pulses per second. If a composite is formed from 3,125 samples, then the output rate to the recorders is $50,000 \text{ divided by } 3,125 = 16 \text{ pulses per second}$. The frequency content of the resulting pulse train is in the audio range and is suitable for recording on ordinary tape and graphic recorders. The graphic recorder provides an immediate view of the data in the field. Data enhancement is possible if raw data is also recorded on a magnetic tape recorder for later playback at a slower speed.

A radar survey is carried out by pulling the antenna slowly along a pre-measured survey line. Radar impulses are transmitted in synchronism with a swept-stylus type graphic recorder. Echo signals are received and processed to shift their frequency downward to a band compatible with the recorders. As the stylus sweeps across the paper, echo signals cause the paper to be darkened at points proportional to the total travel time to the reflector producing the echo. Each pass of the stylus represents a slightly different antenna position as the antenna is moved along. Gradually, as the recorder paper is pulled past the stylus, a pattern of reflective interfaces is generated (see Figure 2). Spacial resolution depends upon the rate at which the antenna is advanced along the ground. A typical pull rate is about 1 mile per hour (18 inches per second). Resolution for 16 pulses per second is 18 inches/sec 16 scans/sec or 1.1 inches between successive scans. If the stylus is swept at 1/4 sec. per sweep, the 16 scan/sec rate will cause the echo pattern to be generated 4 times across the page. The rate at which the recorder paper is pulled under the stylus may be adjusted within broad limits, but a typical rate would be approximately 25 feet of survey line per inch of paper. Distance along the survey line is recorded accurately by means of event marks placed permanently in the recorded data each time a survey point is passed.

Figure 2 shows a typical record and a representation of the radar echo pulses. The recorder detects the presence of an echo signal whenever the level exceeds a preset threshold. The paper is darkened to coincide with every exceedance along any given sweep of the stylus. The pattern of darkened regions on the paper mark the reflective horizons in the earth. Because both positive and negative peaks are printed, dark bands are separated by narrow white lines which are the zero crossings between peaks. The distance down to any reflector is proportional to its depth below the path of the antenna. With the radar technique, variations in depth can generally be resolved to within a few inches.

Accuracy of the depth measurement to any layer depends upon calibration of the radar system. There are five methods used:

1. Correlate the record with the depth of a known reflector;
2. Confirm by drilling to an observed layer;
3. Calculate the wave velocity from electromagnetic constants;
4. Use the common depth point technique;
5. Use the characteristic shape of isolated reflector patterns to compute vertical magnification.

Using the depth to a known reflector such as a water pipe, drain pipe, identified geologic layer, etc., is the most direct and correct method available for vertical scale calibration.

It is applicable only for those cases where the survey area happens to have such known reflectors.

If the depth of an observed reflector is not known, then a confirmatory borehole can be drilled to establish its exact depth as necessary within the survey area. This is a more costly procedure, but it provides an exact depth calibration at each drill location and also allows propagation velocity and effective dielectric constant to be determined.

The third technique provides depth calibration by calculation of wave velocity from dielectric constants. This method is only as accurate as the constants chosen for the materials in the survey area. Table 1 gives typical values for various materials. Note that the dielectric constants vary from 1 to 80. Since propagation velocity varies inversely as the square root of this constant, one can expect a maximum variation in vertical scale from 1 to 9. Note also that water has a very large dielectric constant (80). Thus, the variation of water content in a material can lead to large changes in the wave speed. In spite of these uncertainties for a reasonably well known material, vertical depth scaling can be calculated from available parameters and confirmed by other methods.

The common depth point method requires a separate transmitter and receiver so that the travel time to an identified reflector can be established for known separation between antennas.

The final technique uses an available isolated reflector. The shape of a reflection pattern from an isolated reflection is theoretically a hyperbola with arms at 45° . Because the vertical scale is usually stretched, the angle will appear larger. Using the known horizontal scale on the record, the distortion of the hyperbola can be used to determine magnification of vertical scale. Whenever possible, several calculations in a given area are done and averaged to give a mean value and a band of error.

Depth of penetration in a given material is limited by attenuation of the signal. Attenuation is a function of dielectric loss of electrical conductivity loss which, in a given material, will vary with the amount of water, dissolved salt, temperature, density, and frequency of the radar impulses. Values for attenuation vary from less than 1 db/m for sandy soils to several hundred db/m for sea water. Because of the wide verticality of in-situ values, estimates of penetration are difficult to determine prior to a preliminary radar survey. As a general guide, however, typical penetration in many materials have been found to be 8 to 15 feet. Penetration of up to 75 feet has been reported for water saturated sands in a Massachusetts glacial delta. The antarctic ice shelf has been penetrated to 230 feet. Wet clays, however, will attenuate the signal within 5 feet, and sea water is transparent to less than one foot. It is

important to note that in a layered material a single, highly reflective layer alone can limit penetration into low-loss materials below by preventing the propagation of energy past it. In this case, apparent loss of energy is caused by a reflection rather than by dissipation process.

TABLE 1

Table of Typical Electromagnetic Constants
for Earth Materials at Radio Frequencies

<u>Material</u>	<u>Dielectric Constant</u> (relative)	<u>Resistivity</u> (ohm.m)
Sand, Dry	3	10,000
Sand, 6% water	105	200
Soil, 8% water	4	10,000
Soil, 42% water	30	50
Granite, dry	5-19	-
Granite, typical	15	20,000
Limestone	7-15	300-30,000
Clay	8-12	-
Sandstone, dry	5	1,000
Sandstone, 4% water	11	10 ³
Air	1	00
Fresh Water	80	50-100
Sea Water	80	.25
Ice	4	100-10,000

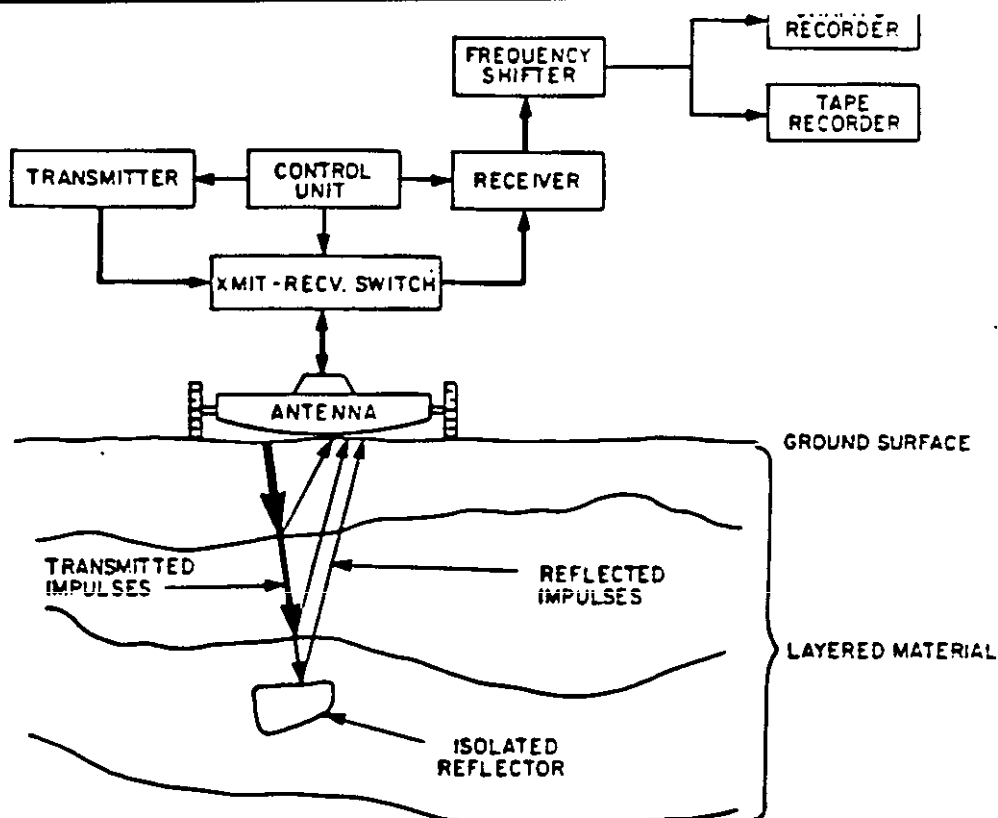


FIGURE 1. RADAR SYSTEM BLOCK DIAGRAM

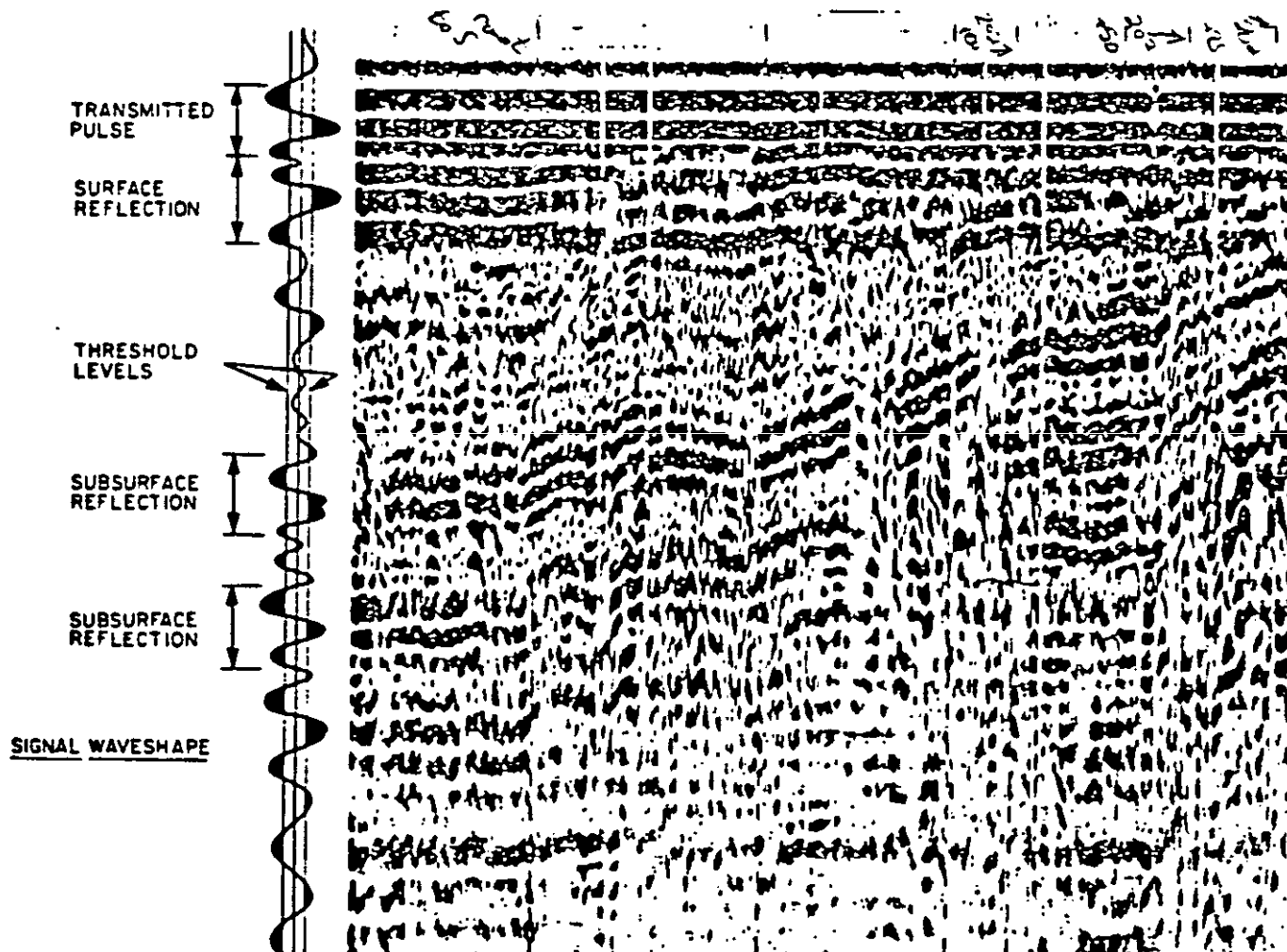


FIGURE 2. TYPICAL RADAR RECORD

APPENDIX B
ELECTRICAL RESISTIVITY SURVEY
METHOD OF INVESTIGATION

APPENDIX B
ELECTRICAL RESISTIVITY SURVEY
METHOD OF INVESTIGATION

General Considerations

The electrical resistivity survey is a method of obtaining shallow subsurface information through electric measurements made at the surface of the earth. The basic parameter is the apparent resistivity determined by passing a known electric current between two electrodes and measuring the resulting voltage drop across two other electrodes. Based on the geometric arrangement of the current and potential electrodes, the apparent resistivity may be calculated. The actual resistivity values are then determined from the layer thicknesses and the corresponding "apparent" resistivity values.

A vertical electric profile can be obtained by increasing the distances between electrodes, thereby providing deeper penetration of the electric current. Since geologic materials have differing electrical characteristics, the apparent resistivity values will be affected by different subsurface conditions.

The relative conductivity (inverse resistivity) of earth materials is proportional to their content of water and dissolved salts or ions. Accordingly, dry sands and gravels, and massive rock formations would have high resistivity values; conversely, moist clays and materials in a saltwater environment would have very low resistivity values.

The interpretation of electrical resistivity data is based upon the comparison of recorded field measurements of apparent resistivity and electrode separation with theoretically computed cases.

Field Procedures for Data Acquisition

Wenner Method

One of the most widely used field arrangements of current and potential electrodes is known as the Wenner configuration. In the Wenner method four electrodes are placed in a straight line and are equally spaced; the two outer electrodes are current electrodes, I_1 and I_2 , and the two inner electrodes are the potential electrodes, P_1 and P_2 (Figure B1).

A vertical electric profile is obtained by conducting a point test in which the electrode spacing is successively increased about a fixed point after each reading.

By using a uniform Wenner configuration of electrodes (constant spacing technique) across an area, changes in apparent resistivity, indicative of lateral changes in materials, can be defined.

Lee Partitioning Method

In a modification of the Wenner configuration, known as the Lee Partitioning array, a third potential electrode, P_0 , is positioned halfway between the other two potential electrodes, P_1 and P_2 (Figure B1).

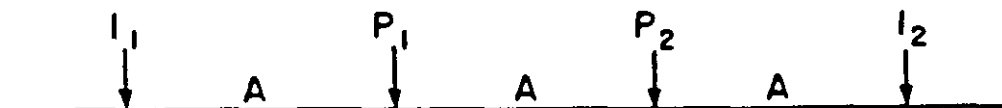
Measurements of the potential drop are made between the three combinations of potential electrodes. In this manner, local horizontal variations in the vicinity of the potential electrodes can be detected.

Schlumberger Method

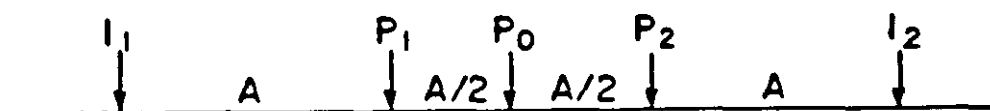
In the Schlumberger electrode arrangement (Figure B1), the spacing between current electrodes is large, at least five times as great as the spacing between the potential electrodes.

The Schlumberger arrangement permits easier discrimination between lateral and depth variations of resistivity.

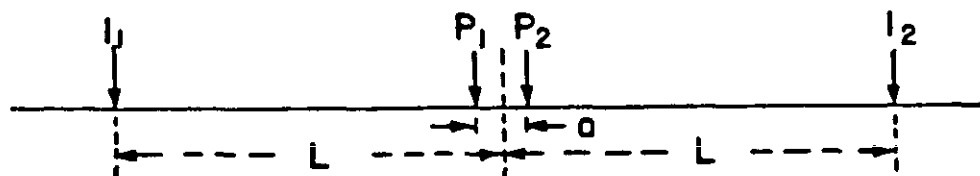
WENNER



LEE MODIFICATION OF WENNER



SCHLUMBERGER

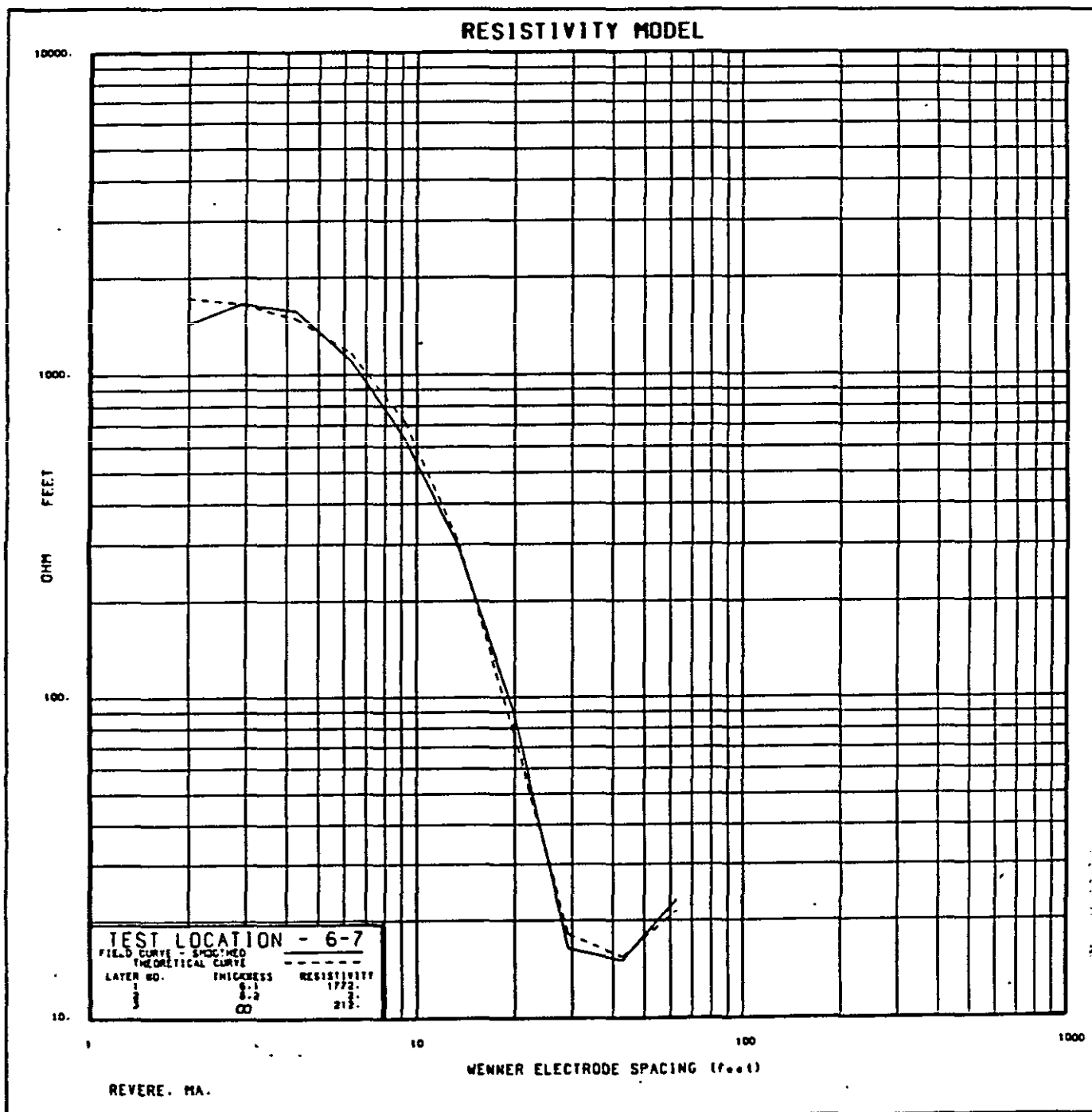


GEOPHYSICAL INVESTIGATION
 REVERE COSTAL FLOOD PROTECTION STUDY
 POINT OF PINES
 REVERE, MASSACHUSETTS
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ELECTRICAL RESISTIVITY
 ELECTRODE CONFIGURATIONS

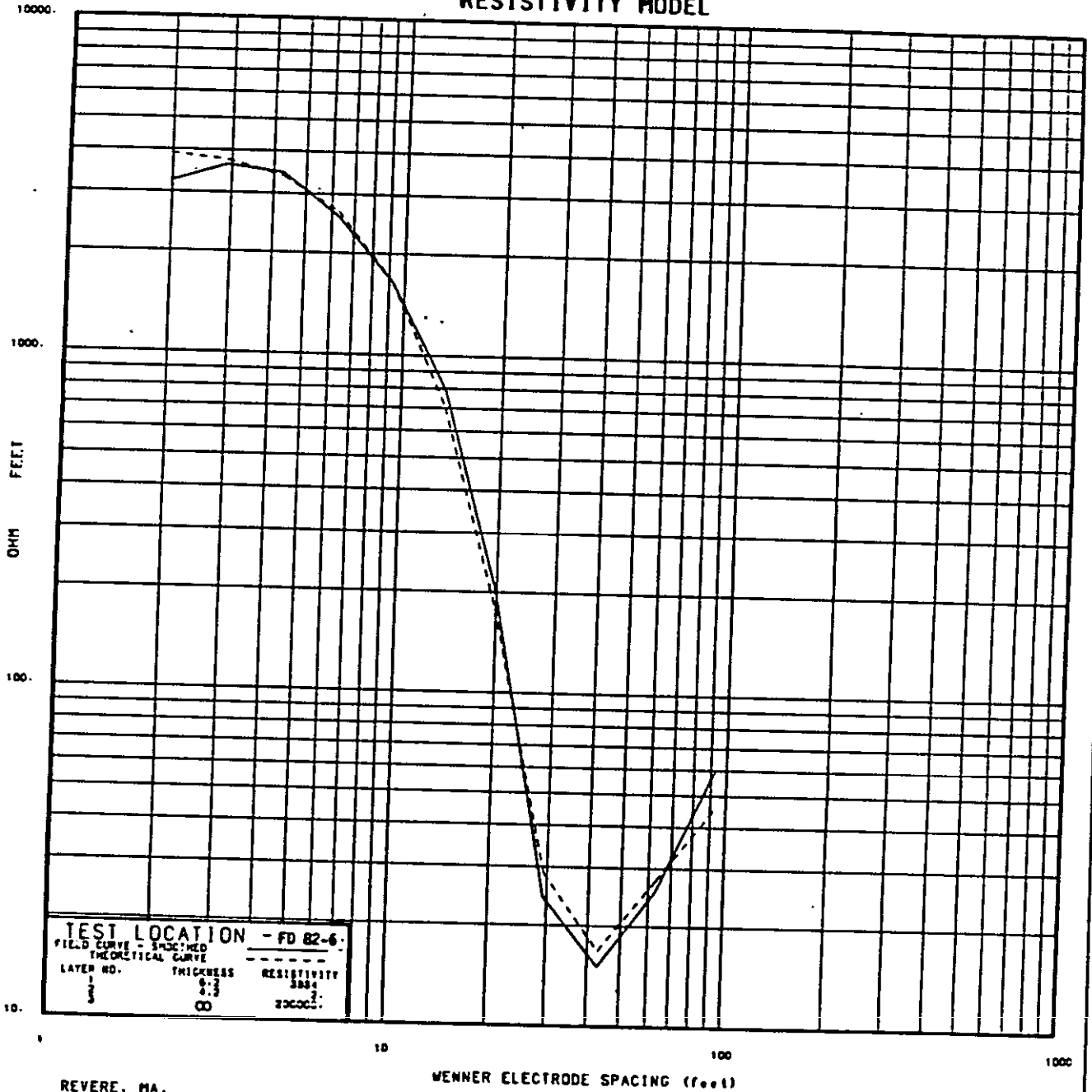
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Figure B-1



<p style="text-align: center;">GEOPHYSICAL INVESTIGATION REVERE COSTAL FLOOD PROTECTION STUDY POINT OF PINES REVERE, MASSACHUSETTS for BRIGGS ENGINEERING & TESTING CO.</p>	<p style="text-align: center;">RESISTIVITY CURVES OBSERVED vs. THEORETICAL PT 6-7</p>
	<p style="text-align: center;">WESTON GEOPHYSICAL CORP. September 1982</p> <p style="text-align: right;">Figure B-2</p>

RESISTIVITY MODEL



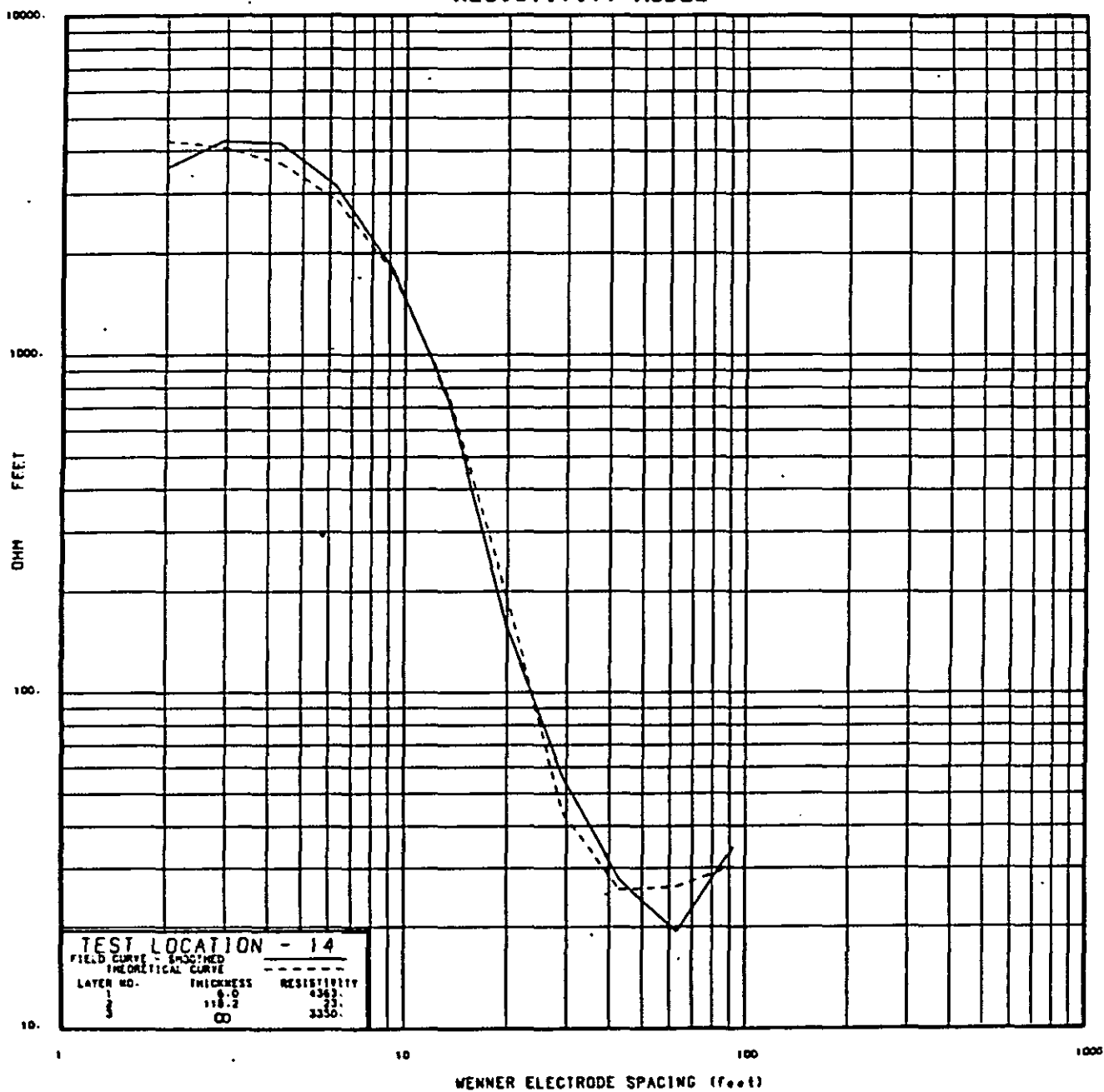
GEOPHYSICAL INVESTIGATION
 REVERE COSTAL FLOOD PROTECTION STUDY
 POINT OF PINES
 REVERE, MASSACHUSETTS
 for
 BRIGGS ENGINEERING & TESTING CO.

RESISTIVITY CURVES
 OBSERVED vs. THEORETICAL
 PT FD82-6

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Figure B-3

RESISTIVITY MODEL

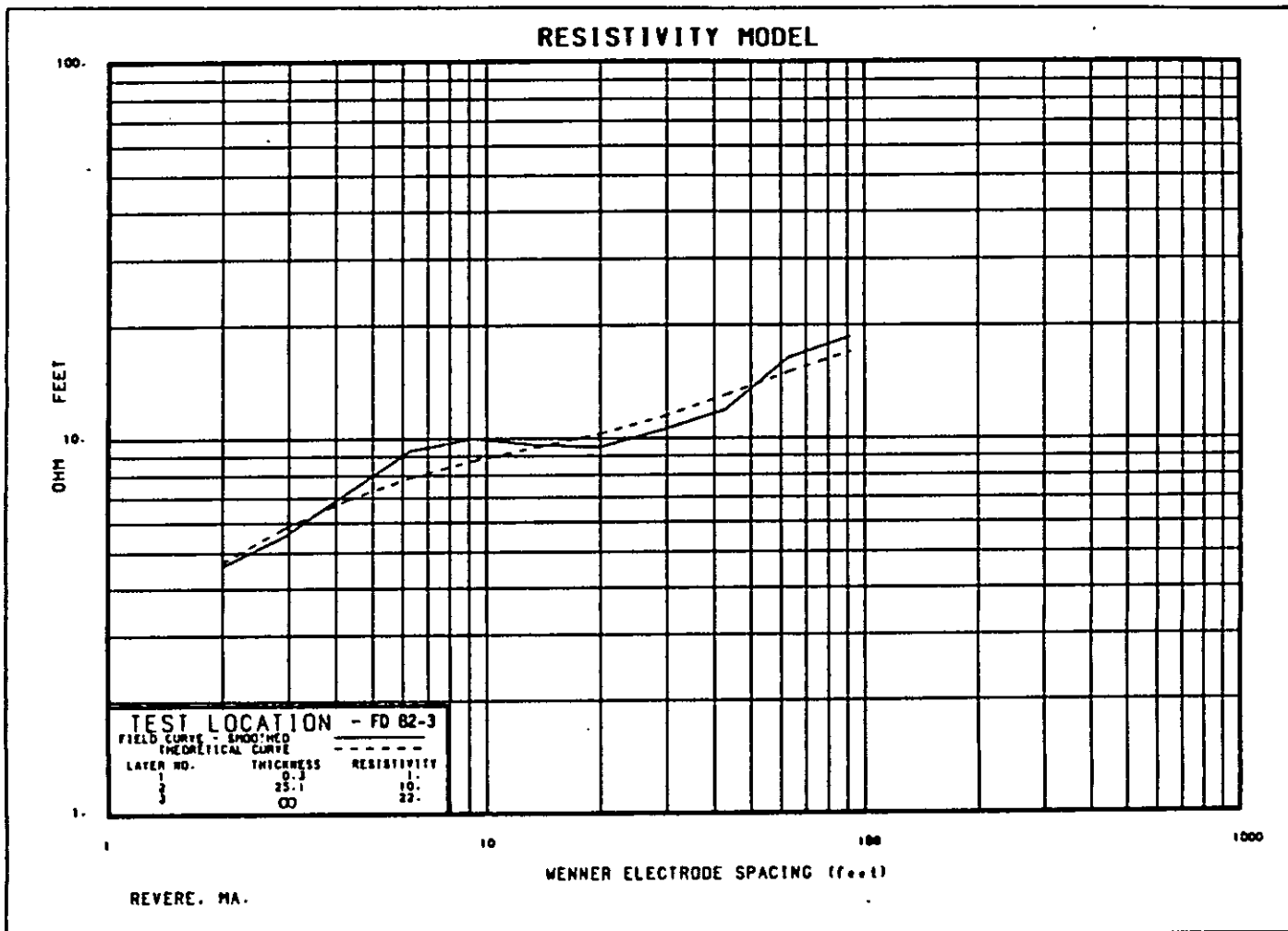


GEOPHYSICAL INVESTIGATION
 REVERE COSTAL FLOOD PROTECTION STUDY
 POINT OF PINES
 REVERE, MASSACHUSETTS
 for
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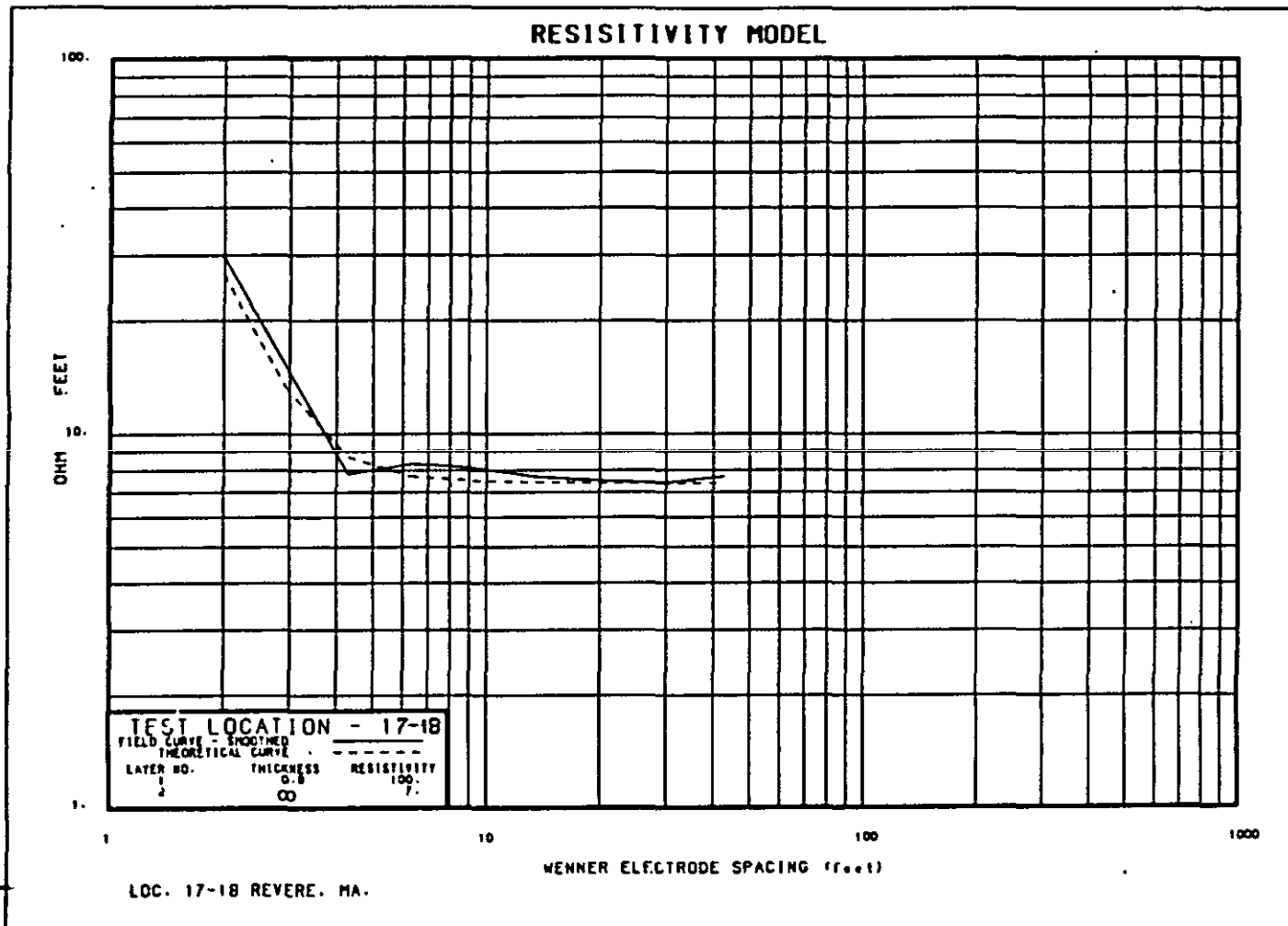
RESISTIVITY CURVES
 OBSERVED vs. THEORETICAL
 PT 14

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Figure B-4



GEOPHYSICAL INVESTIGATION REVERE COSTAL FLOOD PROTECTION STUDY POINT OF PINES REVERE, MASSACHUSETTS for BRIGGS ENGINEERING & TESTING CO.	RESISTIVITY CURVES OBSERVED vs. THEORETICAL PT FD82-3
	WESTON GEOPHYSICAL CORP. September 1982 Figure B-5



GEOPHYSICAL INVESTIGATION
REVERE COSTAL FLOOD PROTECTION STUDY
POINT OF PINES
REVERE, MASSACHUSETTS
for
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RESISTIVITY CURVES
OBSERVED vs. THEORETICAL
PT 17-18

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Figure B-6